

# **No-Clean Soldering to Eliminate CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies**



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**ICOLP\***

**NO-CLEAN SOLDERING TO ELIMINATE CFC-113 AND  
METHYL CHLOROFORM CLEANING OF PRINTED CIRCUIT  
BOARD ASSEMBLIES**

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\* ICOLP is the International Cooperative for Ozone Layer Protection. ICOLP corporate member companies include AT&T, British Aerospace, Compaq Computer Corporation, Digital Equipment Corporation, Ford Motor Company, Hitachi Limited, Honeywell, IBM, Matsushita Electric Industrial, Mitsubishi Electric Corporation, Motorola, Northern Telecom, Texas Instruments and Toshiba Corporation. Industry association affiliates include American Electronics Association, Association Pour la Recherche et Development des Methodes et Processus Industriels, Electronic Industries Association, Halogenated Solvents Industry Alliance (U.S.), Japan Electrical Manufacturers Association, and Korea Specialty Chemical Industry Association. Government organization affiliates include the City of Irvine, California, the Russian Institute of Applied Chemistry, the Swedish National Environmental Protection Agency, the U.S. Air Force, and the U.S. Environmental Protection Agency. Other organization affiliates include Center for Global Change, Industrial Technology Research Institute of Taiwan, Korea Anti-Pollution Movement, National Academy of Engineering, and Research Triangle Institute.

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# FOREWORD

This manual has been prepared jointly by the U.S. Environmental Protection Agency (EPA) and the International Cooperative for Ozone Layer Protection (ICOLP<sup>1</sup>) to aid the electronics industry in its phaseout of ozone-depleting solvents. It will prove useful to both large and small manufacturing facilities because the processes described are applicable to a wide range of manufacturing applications. The manual has been prepared by a committee of experts from industry, the U.S. EPA, and the U.S. Air Force.

In 1987, the U.S. EPA, the Department of Defense, and the Institute for Interconnecting and Packaging Electronic Circuits (IPC) formed an Ad Hoc Solvents Working Group. This working group concluded that military standards and specifications inadvertently discouraged and/or prohibited the use of no-clean processes by prescribing the flux and solvents that must be used in specific manufacturing operations. The working group felt that these constraints were slowing the rate of technological progress and prohibiting manufacturers from considering all alternatives to ozone-depleting solvents. DOD agreed with the committee's recommendation to switch from prescriptive standards to performance standards in a three-phase strategy:

- Phase 1 - Perform a CFC cleaning test to be used as a benchmark against which other alternatives would be compared.
- Phase 2 - Evaluate alternative cleaning formulations against the benchmark and approve those which clean equal to or better than the benchmark.
- Phase 3 - Evaluate no-clean controlled atmosphere soldering processes (See Appendix B for additional details).

In 1990, the U.S. EPA, ICOLP, and IPC helped catalyze interest in perfecting no-clean technology.

introduce new technologies with rapid market penetration and competitive prices. Many of the experts who contributed to these achievements are the authors of this report or are listed in the acknowledgements.

## The Montreal Protocol

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent 1990 and 1992 amendments and adjustments control the production and consumption of ozone-depleting chemicals. At the most recent meeting in Copenhagen in November 1992, chemicals including chlorofluorocarbon 1,1,2-trichloro-1,2,2-trifluoroethane (commonly referred to as CFC-113) and 1,1,1-trichloroethane (commonly referred to as methyl chloroform or MCF) were scheduled for a complete phaseout in developed countries by the year 1996. The phaseout schedule for developing countries was unchanged from the London meeting of Parties (2010 for CFC-113 and 2015 for 1,1,1-trichloroethane) with a vote on further acceleration scheduled for 1995. In addition, the 1992 amendments include a control schedule for hydrochlorofluorocarbons (HCFCs), with a production freeze in 1996, reductions in 2000, 2010, and 2020, and a complete phaseout in developed countries by 2030. HCFCs are not yet controlled for developing countries.

Exhibit 1 lists the countries that have ratified the Montreal Protocol as of May 1993. In addition, many companies worldwide have corporate policies to expedite the phaseout of ozone-depleting chemicals. Exhibit 2 presents the corporate phaseout policies for some of these companies. In addition to providing regulatory schedules for the

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<sup>1</sup> Appendix A presents more detailed information about ICOLP.

Key manufacturing companies participating in the efforts included AT&T, Ford, General Electric, Motorola, and Northern Telecom. This new group of technical experts and the market clout of the ICOLP companies helped to quickly commercialize and implement no-clean technologies. These cooperative efforts have helped to

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*Exhibit 1***PARTIES TO THE MONTREAL PROTOCOL**

Algeria	Ecuador	Liechtenstein	Senegal
Antigua and Barbuda	Egypt	Luxembourg	Seychelles
Argentina	El Salvador	Malawi	Singapore
Australia	EEC	Malaysia	Slovakia
Austria	Fiji	Maldives	Slovenia
Bahamas	Finland	Malta	South Africa
Bahrain	France	Marshall Islands	Spain
Bangladesh	Gambia	Mauritius	Sri Lanka
Barbados	Germany	Mexico	Sudan
Belarus	Ghana	Monaco	Swaziland
Belgium	Greece	Morocco	Sweden
Botswana	Grenada	Netherlands	Switzerland
Brazil	Guatemala	New Zealand	Syrian Arab Republic
Brunei Darussalam	Guinea	Nicaragua	Tanzania
Bulgaria	Hungary	Niger	Thailand
Burkina Faso	Iceland	Nigeria	Togo
Cameroon	India	Norway	Trinidad & Tobago
Canada	Indonesia	Pakistan	Tunisia
Central African Republic	Iran	Panama	Turkey
Chile	Ireland	Papua New Guinea	Uganda
China	Israel	Paraguay	Ukraine
Congo	Italy	Peru	United Arab Emirates
Costa Rica	Jamaica	Philippines	United Kingdom
Cote d'Ivoire	Japan	Poland	United States
Croatia	Jordan	Portugal	Uruguay
Cuba	Kenya	Romania	Uzbekistan
Cyprus	Kiribati	Republic of Korea	Venezuela
Czech Republic	Kuwait	Russian Federation	Yugoslavia
Denmark	Lebanon	St. Kitts and Nevis	Zambia
Dominica	Libyan Arab Jamahiriya	Samoa	Zimbabwe
		Saudi Arabia	

Date: May, 1993

phaseout of ozone-depleting chemicals, the Montreal Protocol established a fund that will finance the incremental costs of phasing out ozone-depleting substances by qualifying developing countries that are Party to the Protocol.

## U.S. Clean Air Act Amendments

The 1990 U.S. Clean Air Act (CAA) amendments contain several provisions pertaining to stratospheric ozone protection. Section 602 of the CAA lists the

ozone-depleting substances that are restricted. These ozone-depleting substances are defined as Class I and Class II substances. Class I substances include all fully halogenated chlorofluorocarbons (CFCs), including CFC-113, three halons, MCF, and carbon tetrachloride. Class II substances are defined to include 33 hydrochlorofluorocarbons (HCFCs). The sections of the CAA that are of importance to users of this manual are discussed below.



*Exhibit 2***OZONE-DEPLETING SOLVENT CORPORATE PHASEOUT DATES****Successful Phaseout:**

A-dec  
 ADC Telecommunications  
 Advanced Micro Devices  
 Alcatel Network Systems  
 Apple Computer  
 Applied Magnetics  
 Aishin Seiki  
 Alps Electric  
 AT&T  
 Cadillac Gage  
 Calsonic  
 Canon  
 Corbin Russwin Hardware  
 Casio Computer  
 Chip Supply  
 Clarion  
 Compaq Computers  
 Conner Peripherals  
 Commins Engine  
 Diatek  
 Fuji Photo Film  
 Fujitsu  
 Harris Semiconductors  
 Hewlett Packard  
 IBM  
 ITT Cannon  
 Japan Aviation Electronics  
 Kilovac  
 Kyocera  
 Mabuchi Motor  
 Matsushita  
 MDM  
 Minebea  
 Minolta Camera  
 Mitsui High-tech  
 Motorola  
 Murata Erie N.A.  
 Murata Manufacturing  
 National Semiconductor  
 NEC  
 Nihon Dempa Kogyo  
 Nissan  
 Northern Telecom  
 NRC  
 Iki Electric  
 Omron

OTC/SPX Pacific Scientific EKD

Ricoh  
 Rohm  
 Sanyo MEG  
 Sanyo Energy  
 Seagate Technology  
 Seiko Epson  
 Seiko-sha  
 Sharp  
 Shin-etsu Polymer  
 SMC  
 Sony  
 Stanley Electric  
 Sun Microsystems  
 Symmons Industries  
 Talley Defense Systems  
 Thomson Consumer Electronics  
 3M  
 Toshiba  
 Toshiba Display Devices  
 Toyota Motor  
 Unisia JECSS  
 Yokogawa Electric

**Future Phaseout:**

Citizen Watch -- 12/93  
 Funac -- 12/93  
 Hitachi -- 12/93  
 Hitachi Metals -- 12/93  
 Isuzu Motors -- 1993  
 Kohyo Seiko -- 12/93  
 Mitsubishi Electric -- 12/93  
 Mitsubishi Heavy Industry -- 12/94  
 Mitsubishi Motors -- 8/93  
 NHK Spring -- 12/93  
 Nissan Diesel Motor -- 1994  
 NSK -- 12/93  
 Olympus Optical -- 12/93  
 Sumitomo Electric -- 12/93  
 Sumitomo Special Metals -- 12/93  
 Suzuki Motor -- 1994  
 Taiyo Yuden -- 12/93  
 Victor Japan -- 11/93  
 Yamaha -- 12/93  
 Zexel -- 8/93

### **Section 604 and Section 605: Phaseout of Production and Consumption of Class I and Class II Substances.**

Sections 604 and 605 of the CAA present phaseout schedules for Class I and Class II substances. The phaseout schedule which applies for any ozone-depleting substances listed in the CAA and in the Montreal Protocol is the more stringent of the two. The CAA is currently being amended to reflect the changes in the phaseout schedule made in Copenhagen. Other substances with ozone-depleting potential are also regulated under the Montreal Protocol and the CAA. While they are not used in solvent cleaning applications, these substances are used in other applications. Section 605 of the CAA specifies provisions for the phaseout of HCFCs. The CAA freezes the production of HCFCs in 2015 and phases them out by 2030. The U.S. EPA has announced that the phaseout schedule for these chemicals will be accelerated to the dates prescribed in the Montreal Protocol. Since these restrictions limit production, any HCFCs recovered or recycled may be used in commercial operations after the applicable phaseout date.

### **Section 608: National Emissions Reduction Program**

Section 608 directs EPA to promulgate regulations by July 1992 requiring that emissions from all refrigeration and cooling equipment (except mobile air conditioners that are covered in Section 609) be reduced to their "lowest achievable levels." While this is not of direct importance in the use of ozone-depleting solvents, it has implications for facilities in which refrigeration and/or air conditioning equipment is used. This section will require air conditioning and refrigeration technicians to be certified to ensure that technicians are familiar with proper recycling and recovery practices. This section also prohibits any person from knowingly venting any of the controlled substances, including HCFCs, during servicing of refrigeration or air conditioning equipment (except cars) beginning July 1, 1992, and requires the safe disposal of these compounds by that date. A "Notice of Proposed Rulemaking"

was published in the Federal Register in December 1992, and the Final Rule was published on May 14, 1993.

### **Section 610: Ban of Nonessential Uses**

Section 610 of the CAA directs EPA to promulgate regulations that prohibit the sale or distribution of certain "nonessential" products that release Class I and Class II substances during manufacture, use, storage, or disposal. In the CAA, Congress defined several products as nonessential, including CFC-containing cleaning fluids for noncommercial electronic and photographic equipment and CFC-propelled plastic party streamers and noise horns. In addition, Congress established guidelines so that EPA may determine that additional products are nonessential. Regulations banning nonessential products that release Class I substances were published on January 15, 1993. The CAA also bans the sale and distribution of certain products releasing Class II substances, including aerosol products, pressurized dispensers, and most foam products after January 1, 1994. Regulations to ban these products are currently being developed by EPA.

### **Section 611: Labeling**

Section 611 of the CAA directs EPA to promulgate regulations by May 15, 1992 requiring labeling of products that contain or were manufactured with Class I substances and containers of Class I or Class II substances. The label will read "Warning: Contains or manufactured with [*insert name of substance*], a substance which harms public health and environment by destroying ozone in the upper atmosphere." The label must clearly identify the ODS by chemical name for easy recognition by average consumers.

On February 11, 1993, the EPA published in the Federal Register a Final Rule for the labeling section of the CAA. The CAA defines three types of products that must be labeled and specifies the time frame by which these products must be labeled as follows:

- Effective May 15, 1993, containers in which a Class I or Class II substance is stored or transported, and products containing Class I substances must be labeled.
  - Effective May 15, 1993, products manufactured with Class I substances must be labeled. However, products manufactured with Class I substances can be
-

temporarily exempted from the labeling requirements of this section if EPA determines that there are no substitute products or manufacturing processes that (a) do not rely on the use of the Class I substance, (b) reduce the overall risk to human health and the environment, and (c) are currently or potentially available. If EPA temporarily exempts products manufactured with Class I substances from the labeling requirement based on the lack of substitutes, the products must be labeled by January 1, 2015. Manufacturers that can show that they have reduced their consumption of Class I substances by greater than 95 percent from 1986 levels are exempt from the product labelling requirements.

- No later than January 1, 2015, products containing or manufactured with a Class II substance must be labeled.

The CAA allows for petitions to be submitted to EPA to apply the labeling requirements to products containing Class II substances or a product manufactured with Class I or II substances which are not otherwise subject to the requirements. This petition process will operate between May 15, 1993 and January 1, 2015. For products manufactured with Class I substances, a successful petition would result in the labeling of a product previously determined by EPA to be exempt. For products containing or manufactured with Class II substances, the petition process could lead to labeling of a product that had been left unlabeled by default.

## **Section 612: Safe Alternatives Policy**

Section 612 establishes a framework for evaluating the environmental impact of current and future alternatives. Such regulation ensures that the substitutes for ozone-depleting substances will themselves be environmentally acceptable. Provisions of Section 612 require EPA to:

- Issue rules which make it unlawful to replace any Class I and Class II substances with a substitute that may present adverse effects to human health and the environment where EPA has identified an available or potentially available alternative that reduces the overall risk to human health and the environment
- Publish a list of prohibited substitutes, organized by use sector, and a list of the acceptable alternatives
- Accept petitions to add or delete a substance previously listed as a prohibited substitute or an acceptable alternative

- Require any company which produces a chemical substitute for a Class I substance to notify EPA 90 days before any new or existing chemical is introduced into commerce as a significant new use of that chemical. In addition, EPA must be provided with the unpublished health and safety studies/data on the substitute.

To implement Section 612, EPA will (1) conduct environmental risk screens for substitutes in each end use and (2) establish the Significant New Alternatives Program (SNAP) to evaluate future introduction of substitutes for Class I substances. EPA is working with the National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and other governmental and nongovernmental associations to develop a consensus process for establishing occupational exposure limits for the most significant substitute chemicals.

The environmental risk screens for the substitutes will be based on a number of environmental criteria, including ODP, toxicity, and likely human exposure. Economic factors will also be considered. EPA will organize these assessments by use sector (i.e. solvents, refrigeration, etc) and will either list a substitute as acceptable, or will restrict uses that adversely affect human health and the environment. Petitioners will have the burden of proof to change a substance's status.

EPA published a "Notice of Proposed Rulemaking" in the Federal Register on May 12, 1993. The Final Rule is scheduled to be published early in 1994.

SNAP will routinely evaluate substitutes not covered in the Final Rule and will classify them based on the results of the risk screens.

## **Acceleration of ODS Phaseout**

All production of Class I substances -- CFCs, halons, methyl chloroform, and carbon tetrachloride -- will be eliminated by January 1, 1996. Limited exemptions for essential uses and for servicing certain existing equipment will be granted as the result of a petition process. At the request of former President George Bush, U.S. producers of these substances reduced the production of ODSs by 50 percent of 1986 levels by the end of 1992. The U.S. is also re-examining the phaseout schedule set forth in the amended Protocol for HCFCs

and is evaluating the possible need for controls on the use of methyl bromide.

## Excise Tax

Effective in 1991, the U.S. Congress placed an excise tax on ozone-depleting chemicals manufactured or imported for use in the United States. This tax provides a further incentive to use alternatives and substitutes to CFC-113 and MCF. The tax amounts, shown in Exhibit 3, are based on each chemical's ozone-depleting potential and apply to purchased chemicals as well as floor stock.

<i>Exhibit 3</i>		
<b>Excise Tax on Ozone-Depleting Solvents</b>		
Calendar Year	Tax Amount	
	Per Pound	
	CFC-113	MCF
1991	\$1.096	\$0.137
1992	\$1.336	\$0.167
1993	\$2.68	\$0.211
1994	\$3.48	\$0.435
1995	\$4.28	\$0.535

Effective January 1, 1993, taxes on ozone-depleting chemicals were increased by a provision in the Energy Policy Act of 1992.

## Other International Phaseout Schedules

### *European Community Directive*

Under the Single European Act of 1987, the 12 members of the European Community (EC) are now subject to various environmental directives.

The members of the EC are Belgium, Denmark, Germany, France, Greece, Great Britain, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain. Council Regulation number 594/91 of March 4, 1991 provides regulatory provisions for the production of substances that deplete the ozone layer. The EC phaseout schedule for CFC-113 production is more stringent than the Montreal Protocol. It calls for an 85 percent reduction of CFC-113 by January 1, 1994 and a complete phaseout by January 1, 1995. For MCF, the production phaseout schedule calls for a 50 percent cut in production by January 1, 1994 and a complete phaseout by January 1, 1996. While all members must abide by these dates, Council Regulation number 3322/88 of October 31, 1988 allows EC members to take even more stringent measures to protect the ozone layer.

### *Other Legislation*

Several other countries have adopted legislation that is more stringent than the terms of the Montreal Protocol. Environment Canada, the federal environmental agency responsible for environmental protection in Canada, has proposed a more stringent reduction program. Under the proposed schedule, all production, import, and export of CFCs for use in Canada must be reduced 75 percent by January 1, 1994 and eliminated by January 1, 1996. Environment Canada has also announced a series of target dates for the phaseout of CFCs in specific end uses. For solvent cleaning applications such as metal and precision cleaning, it mandates a phaseout of CFC-113 by the end of 1994. The production, import, and export of halons and carbon tetrachloride in Canada is to be eliminated by January 1, 1994, and January 1, 1995, respectively. Methyl chloroform production, import, and export will follow the following phaseout schedule: 50 percent reduction by January 1, 1994; 85 percent reduction by January 1, 1995, and 100 percent reduction by January 1, 1996.

Japan has also ratified the revised Montreal Protocol. The recent Ozone Layer Protection Act gives the Ministry of International Trade and Industry (MITI) the authorization to promulgate ordinances governing the use of ozone-depleting compounds. MITI and the federal Environmental Agency have established the "Guidelines for Discharge Reduction and Use Rationalization." Based upon these guidelines, various government agencies provide administrative guidance and advice to the industries under their respective jurisdictions. Specifically, MITI prepares and distributes manuals and encourages industry to reduce the consumption of ozone-depleting compounds through economic measures such

as tax incentives to promote the use of equipment to recover and reuse solvents. On May 13, 1992, MITI requested its 72 Industrial Associations to phase out CFC and MCF use by the end of 1995.

The EFTA (European Free Trade Agreement) countries (i.e., Austria, Finland, Iceland, Norway, Sweden, and Switzerland) have each adopted measures to completely phase out fully halogenated ozone-depleting compounds. Some of the EFTA countries have sector-specific interim phaseout dates for certain solvent uses. Norway and Sweden have eliminated their use of CFC-113 in all applications except textile dry cleaning by July 1 and January 1, 1991, respectively. In addition, Austria will phase out CFC-113 in some solvent cleaning applications by January 1, 1994. Austria, Finland, Norway, and Sweden will completely phase out their use of CFC-113 in all applications by January 1, 1995. Sweden also plans an aggressive phaseout date of December 31, 1994 for MCF.

- Eliminating CFC-113 and Methyl Chloroform in Aircraft Maintenance Procedures.

This manual describes a simply structured program to help eliminate the use of CFC-113 and/or MCF in an electronics manufacturing facility. The manual presents "no-clean" soldering processes available for the electronics industry. The typical product being manufactured will be printed circuit board assemblies that consist of a rigid epoxy glass resin laminate with through-hole components and bottom and/or top-side surface mount technology.

## Cooperative Efforts

The U.S. Environmental Protection Agency (EPA) works with industry to disseminate information on technically feasible, cost effective, and environmentally acceptable alternatives to ozone-depleting substances. As part of this effort, the U.S. EPA and ICOLP are preparing a series of manuals providing technical information on alternatives to CFC-113 and MCF. Based on actual industrial experiences, the manuals aid users of CFC-113 and MCF worldwide in implementing alternatives.

The first manuals in the series are:

- Conservation and Recycling Practices for CFC-113 and Methyl Chloroform
- Aqueous and Semi-Aqueous Alternatives to CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies
- Alternatives for CFC-113 and Methyl Chloroform in Metal Cleaning
- Eliminating CFC-113 and Methyl Chloroform in Precision Cleaning Operations
- No-Clean Soldering to Eliminate CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies

The manual:

- Provides a methodology to select a "no-clean" process
- Includes summary charts that present an overview of the "no-clean" processes discussed in this manual
- Details characteristics of "no-clean" soldering processes
- Outlines the process and equipment characteristics of these alternatives
- Discusses the costs associated with each "no-clean" process
- Presents detailed case studies on industrial applications of these technologies.

This manual will benefit all users of CFC-113 and MCF in the electronics industry. Ultimately, however, the success of any CFC-113 and MCF elimination strategies will depend upon how effectively reduction and elimination programs are coordinated within a facility or organization. The development and implementation of alternatives to CFC-113 and MCF for electronics cleaning present a demanding challenge to any organization. The rewards for successfully implementing these procedures are the contribution to global environmental protection and the increase in industrial efficiency.

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# STRUCTURE OF THE MANUAL

This manual is divided into the following sections:

- **METHODOLOGY FOR SELECTING A CLEANING OR "NO-CLEAN" PROCESS**

This section discusses technical and economic issues that should be considered when selecting a cleaning process.

- **SUMMARY CHARTS**

This section presents two summary charts that match cleaning and no-clean processes with a variety of evaluation criteria.

- **INTRODUCTION TO NO-CLEAN OPTIONS**

This section presents three no-clean choices: no-clean fluxes, no-clean pastes, and controlled atmosphere soldering to enhance process results.

- **PROCESS DETAILS**

This section describes the equipment that is typically associated with no-clean processes.

- **QUALIFICATION OF NO-CLEAN MATERIALS AND PROCESSES**

This section lists information on material and process requirements as well as the test methods used to qualify a no-clean process.

- **ECONOMICS OF NO-CLEAN PROCESSES**

This section details the costs associated with implementing each of the no-clean options discussed in the manual.

- **ENVIRONMENTAL, HEALTH, AND SAFETY ISSUES**

This section discusses issues associated with no-clean processes which might affect human and environmental health and safety.

- **CASE STUDIES OF INDUSTRIAL PRACTICES**

This section provides specific examples of actual industrial applications of no-clean soldering processes.

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# METHODOLOGY FOR SELECTING A CLEANING OR NO-CLEAN PROCESS

The methodology used to select a no-clean process for printed circuit boards (PCBs) must take into account a number of important considerations. These can be grouped into two categories: technical and economic.

## Technical

The factors that determine technical feasibility include:

- Compliance with specifications
- Defect rate
- Customer return issues
- Industry direction
- Cosmetic appearance of the PCBs
- Ability of supplier to meet specifications
- Process flexibility
- Process control
- Process throughput
- Time scale
- Health, safety, and environmental concerns
- Future costs
- Availability of the process

- Process installation
- Process compatibility
- Floor space requirements
- Operating and maintenance requirements
- Other selection criteria related to the specific application

- ***Compliance With Specifications.*** Military or civilian contracts or specifications may strictly define process parameters and performance. For example, military and other high reliability specifications frequently require conformal coatings. Excessive residue often causes surface defects such as vesication. A military contractor may have to ensure that the chosen process will decrease or eliminate this type of defect, whereas this would not be a concern for other types of electronic products without conformal coating. Before selecting any new process, current and future customer requirements should be considered.
- ***Defect Rate.*** This is defined as the rate at which parts fail to meet quality standards. The impact of any cleaning or no-clean process on downstream processes such as testing, post-wave assembly and, subsequent hardware requirements must be evaluated for their effects on defect rate. Consider the possibility that using a new cleaning or no-clean process may require the purchase of new components that are compatible with the new process.
- ***Customer Return Issues.*** This factor is concerned with the percent of units returned, how easily returned units can be repaired, and how well repairs and modifications can be done in the field.

- **Industry Direction.** Investing in a process that is supported by industry direction may decrease costs. Unlike standard equipment, specialized equipment frequently means higher costs for parts and service, limited reliable sources for providing technical assistance, and higher risks.
  - **Cosmetic Appearance of the PCBs.** Although visual appearance unrelated to performance is becoming less important, some customers still demand visual standards of cleanliness for electronic components.
  - **Ability of Suppliers to Meet Specifications.** The quality of incoming boards and components is critical to the success of a no-clean process. It is essential that suppliers deliver boards free from oxidation and other contaminants since there will be no further cleaning during the manufacturing process. In cases where boards will be cleaned using an alternative process, incoming board cleanliness is less of a concern.
  - **Process Flexibility.** This factor is defined by the number of different types of technology that can be efficiently soldered with the new process. It also considers compatibility with typical materials.
  - **Process Control.** Process control refers to the ease of operation and manipulation of a soldering or cleaning process. Simple processes are often better from the standpoint of process control. A second part of this issue involves the tools and techniques that insure the process is operating as expected. A process that cannot be easily controlled or audited is not desirable.
  - **Process Throughput.** Throughput is more important to the success of a no-clean process than it is to an alternative cleaning process. No-clean soldering may not be applicable for some low-volume manufacturing processes or for shops using a large number of different components. Low-volume shops often buy small quantities of components which may sit for several years in inventory. While the components may arrive clean from the supplier, they are likely to become contaminated while in storage -- a factor which adversely affects solderability. In high-volume shops, components move quickly out of inventory and are less likely to become contaminated.
  - **Time Scale.** The conversion of an existing process may require the removal of old equipment, the installation of new equipment, connecting the services, performing acceptance trials, establishing manufacturing protocols, and implementing them into production. It may be necessary to begin with zero planned production initially, and then slowly ramp-up to full production.
  - **Health, Safety, and Environmental Concerns.** The U.S. EPA is conducting an overall risk characterization for substitutes under Section 612: Safe Alternatives Policy of the Clean Air Act of 1990. This involves a comprehensive analysis based on ozone-depletion potential, flammability, toxicity, exposure effects, energy efficiency, degradation impacts, air, water, solid waste/hazardous waste pollution effects, environmental releases, and global warming potential.
  - **Future Costs.** This consideration requires evaluating conditions such as escalating waste disposal costs and major expenditures associated with pending control legislation.
  - **Availability of Process.** "Availability" is different from "industry direction." "Availability" concerns whether vendors can provide the equipment and supplies for the process to be implemented. For example, some alternatives might be available only from a few vendors in specific geographic areas.
  - **Process Installation.** This is the work that will be required to put the system into production and includes physical installation of the process, material handling considerations, and employee training.
  - **Process Compatibility.** The fewer the number of changes caused by the proposed process, the more likely that the changeover will be successful. Upstream and downstream process adjustments required for a changeover should be considered.
  - **Floor Space Requirements.** The total amount of space available and its value have a significant impact on process selection. In some instances permits may be required before installing a new process. When compared to traditional vapor degreasing, no-clean processes will require less floor space while most alternative cleaning processes will require more floor space.
  - **Operating and Maintenance Requirements.** Each new process will require the development of operating and maintenance procedures. In some instances a new process might require additional labor to operate and may require special operator training, while in others, the amount of necessary labor may decrease.
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## Economic

The factors that determine the economic feasibility include:

- Cleaning process and equipment
- Waste stream
- Plant size considerations
- Process time
- Process material consumption
- Labor
- Utility costs

- **Labor.** Changes in the amount or skill level of labor required to perform a particular assembly process may affect process costs. In no-clean processes, the labor costs associated with operation of the cleaning equipment are eliminated.
- **Utility Costs.** The price and consumption of electricity, water, and waste disposal to public utilities should be considered in evaluating a process.

- **Cleaning Process and Equipment.** The cost associated with retrofitting or purchasing new equipment as well as the savings realized by eliminating other equipment should be considered.
- **Waste Stream.** The type and quantity of waste generated as a byproduct from a manufacturing process can impact overall costs. Eliminating the solvent cleaning process will eliminate the expense and environmental risk previously associated with disposal of the solvent.
- **Plant Size Considerations.** An increase in necessary floor space may require expansion or remodeling of a manufacturing facility.
- **Process Time.** The amount of time which it takes to produce a finished board may have a direct impact on the cost associated with a particular board assembly process. In most cases, it takes less time to solder a board using a no-clean process than it does to solder, clean, and dry boards in a traditional process. In general, the longer it takes to produce a board the higher the overall cost of the process will be.
- **Process Material Consumption.** The amount of raw materials consumed in the production process will greatly affect process costs. Raw materials to consider include flux, solder, and in some cases, nitrogen. Solvent costs are eliminated in no-clean processes.



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## SUMMARY CHARTS

This section focuses on two charts which highlight technology applicable to specific requirements. The remainder of the manual provides additional detail about the various options.

### Cleaning Options

The cleaning options chart shown in Exhibit 4 presents a range of fluxing and cleaning combinations that may be used successfully with different types of products. Reviewing these combinations is a first step in selecting a process.

When rosin fluxes are used, cleaning with hydrocarbon/surfactants or with saponifiers may be necessary. With water soluble flux/paste, plain water cleaning is preferred although aqueous saponified or semi-aqueous cleaning are also applicable. No-clean processes may be applicable for rosin-based flux formulations used with through-hole, surface mount and mixed component single- and double-sided boards.

### Summary Matrix

The second chart, shown in Exhibit 5, provides brief, relevant comments on the costs, applicability, strengths, and weaknesses associated with equipment configurations of six no-clean processes discussed in this manual.

A brief explanation of some of the criteria displayed in Exhibit 5 follows:

**Component Issues.** Issues of concern include corrosion, failure of seal, effects on plastics, effects on functional performance, removal of markings, and the potential to trap flux residues.

**Defect Rate.** This concern refers to the soldering defect rate associated with a no-clean process relative to traditional soldering processes.

**Waste Stream Issues.** Process control, volume, local regulations, and management decisions influence this highly localized issue. Waste stream reductions are realized with no-clean processes since disposal of spent solvent is eliminated. In addition, there are no wastewater issues as there are in aqueous and semi-aqueous cleaning processes. When soldering is performed in a controlled atmosphere, less lead/tin solder dross is formed.

**Health and Safety Issues.** These issues include toxicity, flammability, odor, VOC concerns, and occupational exposure to hazardous chemicals used in no-clean processes.

**Idle Time Cost.** Since soldering equipment is often used less than 100 percent of the time, factoring in the cost of ventilation, nitrogen flow (for controlled atmosphere systems) is important.

**Process Cost.** The associated cost per square meter of product is determined by a number of variables at the local level. The chart, however, presents a likely reduction in cost by implementing a no-clean process.

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exhibit 4

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*Exhibit 5***MATRIX COMPARING NO-CLEAN PROCESSES**





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# INTRODUCTION TO NO-CLEAN OPTIONS

Successful implementation of no-clean soldering processes requires a detailed understanding of both the soldering process and the materials used in the no-clean process. As with traditional assembly processes, the selection of fluxes and equipment will continue to be an area in which there are a wide variety of available options, so users must consider all of the properties, capabilities, and limitations associated with each no-clean option. When considering the use of a no-clean flux, no-clean paste, or controlled atmosphere, select materials and equipment with care since the variability associated with no-clean processes is greatly reduced relative to traditional soldering operations. To fully take advantage of this new technology, users must acquire new knowledge and must form sound judgements based upon engineering data and experience.

Switching to a no-clean processes will sometimes require a shift in thinking on the part of engineers, management, and/or customers, due to the small amount of harmless residue which may remain on a PCB that is no longer cleaned after soldering. While the residue may be benign and cause no damage to the functional quality of the board, cosmetic quality may be lowered. In any case, each potential no-clean user must weigh for themselves the importance of cosmetics in their final product.

Eliminating post-solder cleaning necessitates that greater attention be paid to the boards and components used in the manufacturing process. Boards and components must be sufficiently clean prior to the soldering process, since residues will no longer be removed in a post-solder cleaning step. Many of the residues found on boards after testing of a no-clean system can be attributed to the boards and components arriving at the plant uncleaned. Users of no-clean systems must ensure that their suppliers can meet the cleanliness requirements associated with the no-clean soldering process. In addition, proper handling of boards and components prior to soldering becomes more vital when using a no-clean process.

There are several options available to manufacturers which will allow for soldering without subsequent cleaning. These are:

- Continue normal soldering using an RMA flux or paste, but eliminate post-solder cleaning
- Use a low-residue type flux or paste and eliminate the cleaning process
- Change the method of flux application for wave soldering so that the amount and placement of flux is more precisely controlled and the cleaning step is eliminated.

In addition, some manufacturers may choose to carry out the soldering operation in a controlled atmosphere to reduce the level of oxygen present during soldering. Benefits associated with this switch include better cosmetics, better solder wetting characteristics, improved solder joint quality, and reduced solder dross. Potential drawbacks associated with the use of a controlled atmosphere include increased bridging, which is often related to board design. However, as more sophisticated equipment is introduced, the incidence of bridging in controlled atmosphere soldering will decrease.

This section provides a brief overview of the use of alternative flux and paste materials as well as describes soldering in a controlled atmosphere.

## No-Clean Wave Solder Fluxes

If soldering with a traditional flux and simply eliminating the cleaning process yields unsatisfactory results, consideration should be given to changing the flux formulation. No-clean is the classification given to fluxes whose residues are benign and may be left on a printed circuit board (PCB) after the soldering operation is completed. Thus, no post-solder cleaning operation is required and the use of CFC-113 or methyl chloroform (MCF) is eliminated. There are two general types of no-clean wave solder fluxes available at the present time: low-solids no-clean fluxes and the less frequently used high-solids no-clean fluxes. In addition, a new generation

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of water-based low-residue fluxes is currently being developed. If successfully developed, water-based low-residue fluxes will be useful in meeting stringent VOC requirements in many nonattainment areas.

### ***Low-Solids No-Clean Fluxes***

A typical low-solids, low-residue flux will contain 0.5 to 4 percent solids, while traditional rosin fluxes contain 15 to 40 percent solids. Exhibit 6 shows a typical chemical composition of a traditional flux and a low-solids flux. The reduced solids content results in less post-solder residue remaining on the board, ideally eliminating the need for cleaning.

Due to the decreased solids content of the flux, flux placement on the board becomes extremely important in ensuring that an adequate solder joint will be formed and in achieving acceptable cosmetic appearance. Enough flux must be deposited on the board to facilitate the formation of a good quality solder joint, but excess flux will result in increased residues, thereby possibly interfering with bed-of-nails testing and/or adversely affecting board cosmetics. For this reason, traditional foam and wave fluxing methods may be considered unsatisfactory as they can result in an excessive amount of flux being deposited on the PCB. Therefore, manufacturers using low-solids fluxes often opt for the use of an alternative flux delivery method. Spray fluxers are a popular alternative because the amount and pattern of flux delivered can be closely controlled. Spray fluxing will be discussed in greater detail in the portion of this manual devoted to equipment requirements.

#### Low-Solids No-Clean Fluxes

- Contain only 0.5 to 4 percent solids
- Eliminate the need for post-solder cleaning for cosmetic purposes because their reduced solids content results in less residue
- Can be used in existing wave soldering machines
- May be applied with a variety of fluxing methods (foam, wave, and spray)
- May affect solderability and board cosmetics
- May require adjustment of the amount and pattern of flux deposited
- May leave flux residue that can make product testing more difficult, especially in cases where "bed-of-nails" testing is conducted.

### ***High-Solids No-Clean Fluxes***

High-solids fluxes are the other no-clean flux option. They are similar in nature to their low-solids counterparts, but with solids contents in the range of 15 to 40 percent. High-solids no-clean fluxes have been used in Europe for several years, but they have failed to gain widespread acceptance in the U.S., primarily due to cosmetic preferences of PCBs. The higher concentration of flux residue which remains on the board may also result in increased tackiness, test probe penetration problems, electrical problems, and reduced aesthetics. These residues, however, lock corrosive residues in a safe matrix, thereby providing a method for controlling long-term corrosion caused by stronger activation packages.

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exhibit 6

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#### High-Solids No-Clean Fluxes

- Contain 15 to 40 percent solids.
- Used in Europe and Japan, but not widely in the U.S.
- May result in increased tackiness, reduced testability, and electrical problems. These factors may necessitate changes in the test probe and clamp used.
- May produce boards that appear to be unclean but which meet all test criteria.

## No-Clean Solder Pastes

The simplest way in which a reflow soldering process can be converted to no-clean is to continue soldering using a traditional RMA paste and simply eliminate the post-solder cleaning step. In cases where this switch does not result in a satisfactory board, however, manufacturers may choose to switch to a low-residue no-clean solder paste. These pastes can be left on the board, thereby eliminating the need for solvent cleaning using CFC-113 or MCF after reflow soldering. After reflow, no-clean pastes leave a small amount of residue on the board which is usually not visually detectable by the naked eye.

#### Low-Residue No-Clean Solder Pastes

- Eliminates need for cleaning after reflow soldering processes
- Leave harmless residue which is not visible with the naked eye
- May require use in a controlled atmosphere to produce adequate solder joints.

## Controlled Atmosphere Soldering

In most cases, excellent soldering results can be achieved in a no-clean process conducted in an air atmosphere. However, soldering in a controlled atmosphere will improve solder joint quality, increase yield as a result of reduced wetting defects, improve cosmetic appearance by reducing post-solder residue, and significantly reduce the waste stream as less solder dross is produced.

In a controlled atmosphere soldering process, an inert gas, usually nitrogen, is pumped into the soldering chamber in order to reduce the level of oxygen present at the time the soldering operation takes place. Soldering in a controlled atmosphere may reduce the amount of flux required to produce an acceptable solder joint. This reduction, in turn, can reduce post-solder residue and eliminate the need for post-solder cleaning.

Potential users of controlled atmosphere soldering should be aware of several U.S. patents which apply to soldering processes carried out in a controlled atmosphere. These patents (see Appendix C for the complete text) are held by the Linde Division of Union Carbide Industrial Gases:

- Patent #5121875 -- Wave Soldering Under an Inert Atmosphere
- Patent #4821947 -- Soldering Without Flux
- Patent #5071058 -- Control of Oxygen in a Soldering Process
- Patent #4823680 -- Laminar Diffusers

Additional patents are held by other equipment manufacturers and gas suppliers, and licensing charges may apply with the use of controlled atmosphere soldering.

As a result of the switch to a controlled atmosphere, several changes in the soldering process occurred. In the case of wave soldering, the controlled atmosphere can reduce the need for flux if a sufficiently low level of oxygen can be achieved in the soldering module. In some instances, manufacturers will be able to eliminate the use of a traditional or a no-clean flux in favor of what is commonly referred to as a preparation fluid (normally a solution of 1 to 2 percent adipic acid in alcohol). Formic acid, injected as a gas, has been used in some applications to reduce dross on the solder wave and to promote solder wetting.

Another benefit provided by soldering in a controlled atmosphere is improved solder wetting. One supplier of industrial grade nitrogen conducted extensive studies in

which the wetting force over time was measured in air and nitrogen atmospheres using a wetting balance. The tests were conducted using copper wires which had been dipped into activated rosin flux. Exhibit 7 presents the results of the study and shows that, not only is the wetting force for copper greater in a nitrogen atmosphere, but the wetting time is approximately 32 percent shorter as well.

#### Controlled Atmosphere Soldering

- Reduces oxygen levels in the solder area significantly by using nitrogen; levels below 10 ppm are possible
  - Can be used in conjunction with no-clean fluxes and no-clean solder pastes
  - Can be used in both wave and reflow soldering processes
  - May completely eliminate the need for flux
  - Can be easily adapted to existing equipment by the use of several available retrofit options
  - Improves joint quality and reduces wetting defects and solder dross
  - May result in increased bridging.
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Exhibit 7

## PROCESS DETAILS

As mentioned earlier, switching to a no-clean soldering process can be accomplished through several process changes, including the removal of the cleaning step, changing the method of flux application in wave soldering, changing the flux or paste formulation, and soldering in a controlled atmosphere. Deciding which of these options is most beneficial depends on a number of factors which are specific to each manufacturing facility.

This section describes these options as they apply to both wave soldering and reflow soldering. In addition, a detailed discussion of equipment and process modifications is presented for each option.

### No-Clean Wave Soldering

Traditional wave soldering operations consist of two primary pieces of equipment: a conveyorized wave solder machine and a solvent cleaning machine. No-clean wave soldering operations require only the conveyorized wave solder machine. Although these machines may differ in size, all have the same basic modules.

The primary considerations in switching to a no-clean wave soldering process include the flux selection, the method of flux application, and the process profile. This section describes no-clean wave soldering operations and discusses the critical process details which affect the success of a no-clean operation.

#### No-Clean Wave Soldering

- Can be performed in an air or controlled atmosphere
- Can often be implemented using existing equipment and no-clean fluxes with little or no retrofit
- Requires little additional worker training because Operation is similar to traditional soldering
- Eliminates costs associated with purchase, operation, and maintenance of cleaning equipment.

#### ***No-Clean Wave Soldering in Air***

Wave soldering without cleaning can be performed in an air atmosphere in a variety of ways. The first is to continue using traditional fluxes while simply eliminating the cleaning process. This is the simplest method and should be tested before any investments are made in equipment retrofits or

purchases. In most cases, the results of such a test will be excessive residue and/or testability issues which are unacceptable to the manufacturer and/or the customer. As a consequence, additional process changes may be required to convert to a no-clean process.

The logical next step is to change the flux formulation and possibly the method of flux application. A change in flux formulation usually means a switch to either a low-solids no-clean flux or a high-solids no-clean flux. Numerous formulations of these fluxes are currently available on the market, so manufacturers are able to test a large number in their current equipment.

A change in the method of flux application involves the addition of a stand-alone fluxing module or retrofit of the existing soldering machine. There are three types of flux application methods which have proven successful in no-clean applications: foam, wave, and spray. General performance characteristics of each of the flux application methods are shown in Exhibit 8. The

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*Exhibit 8***PERFORMANCE CHARACTERISTICS OF FLUX  
APPLICATION METHODS**

following is a summary of each method, how it works, and issues associated with its use.

- **Foam Fluxing.** Foam fluxing has traditionally been the most widely used method of flux application in the electronics industry. In this process, flux is bubbled up to a foamy head by forcing air through one or more porous stones or tubes located under the flux bath. The PCB then passes over the foam head and flux is deposited on the board. To reduce safety hazards, it is possible to substitute nitrogen for air in this application method.

The benefits associated with the use of foam fluxing include its current widespread use, the absence of any uncontrollable health or safety impacts, and its relatively low cost. Drawbacks of using foam fluxing center on the characteristics of flux deposition. When using a foam fluxer, controlling the amount of flux deposited on a board is difficult. In addition, it is possible to deposit flux on the top side of the board. This can have significant implications in a no-clean process because it results in more flux residue, which can cause subsequent cosmetic and/or testing problems.

- **Wave Fluxing.** Wave fluxing is similar to wave soldering in that the PCB passes over a wave of flux, just as it later passes over the solder wave. Wave fluxing is considered versatile because most liquid fluxes can be applied in this manner. As with foam fluxing, the major difficulties in wave fluxing are controlling the amount of flux deposited, and controlling the tendency to deposit flux on the top side of the board. Maintaining the proper wave height is vital to avoid applying too much or too little flux. Some new wave fluxing equipment reliably controls the amount of flux deposited. Other manufacturers, however, are still working to achieve this control in their equipment.
- **Spray Fluxing.** In some cases, the traditional methods of flux application -- foam and wave fluxing -- are not used in no-clean wave soldering because they may apply too much flux. Instead, many users are opting for spray fluxing, a method in which a thin layer of flux is applied through a finely controlled mist. Spray fluxers have the advantage of being able to consistently apply the same amount of flux in the same pattern while also reducing flux consumption. In addition to maintaining consistency, spray fluxers allow deposit rates to be varied easily and closely controlled. Recently, a new type of spray fluxer was introduced to the market. This fluxer is based on

precision microjets of flux which are triggered on and off as the flux applicator moves quickly under the board. This equipment can achieve flux deposition thickness of 600 micrograms per square inch and higher. In addition, the application device exhibited no problems with clogging during development and testing.

While all flux application methods have safety risks associated with them, these risks are often greater with spray fluxers. Since fluxes traditionally contain significant amounts of flammable solvents, special safety measures are needed to reduce both flammability risks and odors associated with the flux vapor. The flammability and vapor exposure risks are generally higher in spray fluxing than in foam or wave fluxing. These increased risks necessitate that spray fluxing take place in well-ventilated areas which are equipped with sufficient fire control devices.

If spray fluxing is selected, the fluxing module on the soldering machine can be replaced with a spray unit. Another option for converting to spray fluxing is to purchase a new fluxing unit which can be placed before the soldering machine as a new module. Several companies manufacture stand-alone spray fluxers which can be installed on an existing production line. These units usually consist of a short conveyor with a spray unit mounted under the conveyor and a hood mounted above the conveyor. Proper ventilation and fire control devices are required.

With the exception of the possibility of a new flux application method, the remaining steps in the soldering process are the same for no-clean processes as for traditional soldering operations. However, the process window (a measure of the flexibility of a soldering process) is reduced when using a no-clean process.

After the flux has been applied to the PCB by foam, wave, or spray fluxing, the board moves into the preheat zone of the wave soldering machine. Preheating of the board is an important part of the soldering process as it performs several vital functions:

- reduces the risk of thermal shock which can damage the board and/or components
- removes flux volatiles
- activates the flux chemistry
- removes the oxide layer on the board.

The more volatile no-clean flux chemistry results in a process window much smaller than that associated with

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conventional fluxes. As a result, specific preheat temperatures and solder contact angles are vital to ensure proper flux activation and the formation of good quality solder joints. Under- or over-heating of the board must be avoided as the flux may either not activate or may burn. Production engineers should work with the flux manufacturer to determine the optimum soldering process profile.

#### No-Clean Wave Soldering in Air

- Three options: 1) existing equipment with existing flux, 2) substitute a no-clean flux, 3) substitute an alternative flux application method
- Can be performed with foam, wave, or spray fluxing
- Spray fluxing can be implemented relatively cheaply due to reduced operating costs
- Process window becomes smaller than in traditional soldering.

### ***Retrofitting Existing Equipment for Controlled Atmosphere Soldering***

No-clean soldering in air frequently does not produce the highest quality, the most satisfactory cosmetics, and the desired waste stream characteristics. Consequently, some manufacturers choose to perform the wave soldering operation in a controlled atmosphere. In many cases it is possible to retrofit existing wave solder machines for controlled atmosphere soldering.

For operation with a controlled atmosphere, traditional wave soldering machines must be retrofitted with a hood to control the oxygen content in the soldering module. The hood seals a portion of the machine so that nitrogen can be pumped in and oxygen displaced. At the present time, at least two manufacturers offer nitrogen retrofit packages. Regardless of the retrofit chosen, users should be aware that there are at least four patents (see Appendix C for copies of these patents) owned by a major supplier of industrial gases which apply to the use of controlled atmospheres in soldering processes.

One type of retrofit which facilitates using a controlled atmosphere is a hood which is placed only over the solder pot area only. This is a simple retrofit which can be completed in a short amount of time in the manufacturing facility. Although it is the least expensive available retrofit for soldering in a controlled atmosphere, it is also the least gas efficient. The other retrofit is a hood which covers both the preheat modules and the solder pot. This retrofit results in low oxygen levels, while using less nitrogen than the solder-pot-only retrofit. Due to the size of the "long" hood, this retrofit is sometimes installed by the wave soldering equipment manufacturer. The installation procedure may require that the entire wave soldering machine be shipped to its manufacturer.

### ***New Equipment Options for Controlled Atmosphere Soldering***

Three types of specially designed equipment are available for no-clean soldering operations. The first, an open-tunnel machine, allows an uninterrupted flow of boards to be soldered in a controlled atmosphere. The second, a sealed-tunnel machine, can achieve extremely low levels of oxygen in the solder area but does not allow an uninterrupted flow of boards. A third option uses a partially-closed tunnel with carefully focused nitrogen injected to reduce oxygen concentration using less nitrogen than other methods. These machines differ significantly in mechanical design.

- ***Open-Tunnel.*** An open-tunnel wave soldering machine has curtains at the entrance to the preheat module and at the exit of the solder module to trap nitrogen in the machine and to prevent significant amounts of oxygen from entering the machine. However, because the curtains on these machines are limited in their ability to trap sufficient nitrogen within the tunnel, open-tunnel machines may require a significant amount of nitrogen to achieve sufficiently low oxygen levels. Despite the fact that open-tunnel machines may consume more nitrogen than sealed-tunnel machines, they are popular because they allow continuous high-volume processing of boards or pallets.
- ***Sealed-Tunnel.*** For operations which require strict control of the atmosphere in the preheat and solder modules, a sealed-tunnel wave soldering machine is currently available on world markets. In these machines, entrance to and exit from the controlled atmosphere area of the machine is made through a vacuum chamber. The principle behind this procedure is similar to that of an airlock. The product

(board or pallet) moves into the entrance vacuum chamber and all of the oxygen in the chamber is removed. Pumps then fill the chamber with nitrogen and the chamber is opened to allow the product to move to the preheat module. After the product passes over the solder wave, it moves into the exit vacuum chamber. Nitrogen is then removed from the exit vacuum chamber before the product exits. These vacuums ensure that little oxygen enters the machine, thereby providing strict control of the atmosphere. The major drawback associated with these machines is their relatively low throughput compared to that of their open-tunnel counterparts.

- ***Partially-Closed Tunnel.*** A third type of controlled atmosphere soldering system has recently been developed which combines a dual wave with a focused nitrogen supply in a partially closed tunnel. Unlike the other machines, the nitrogen gas is not captured around the solder pot. Rather, it is introduced from focused slots immediately ahead of and immediately after each solder wave. The focused use of nitrogen results in a significantly lower nitrogen consumption when compared with the open- and sealed-tunnel equipment. Users of this third design have reported satisfactory soldering with a decrease in solder bridging. This type of focused nitrogen system can also be installed as a retrofit on existing soldering equipment with relatively little difficulty. The safety of this design is comparable to that of other nitrogen soldering systems. However, since there is no actual tunnel, safety enhancements should include special ventilation for fumes and solder spatter shields.

In the case of either the open-, sealed-, or partially-closed tunnel machines, if the objective is to minimize oxygen levels, special attention must be given to the location(s) where the oxygen concentration levels are measured. In order to make an accurate comparison between the three types of machines, oxygen levels on each machine must be measured using the same oxygen meter at a similar location. The use of formic and other acids in flux formulations may adversely affect the performance of some oxygen analyzers. Care must be taken in the selection and operation of the analyzer.

## No-Clean Reflow Soldering

The simplest way to convert from traditional reflow soldering with a standard RMA paste to a no-clean reflow process is to leave the soldering process unchanged and eliminate the post-solder cleaning step. To clean stencils, a number of cleaning processes can be used in place of

CFC-113 or MCF. These include isopropyl alcohol, semi-aqueous cleaners, and other cleaners. Many manufacturers have been successful in phasing out CFC-113 and MCF cleaning in this manner.

However, if this simple modification does not provide adequate board quality characteristics, a switch to a low-residue no-clean solder paste may be warranted. As with wave soldering, additional cosmetic quality can be achieved by conducting the soldering operation in a controlled nitrogen atmosphere.

While the low-residue paste can often be substituted for the traditional RMA paste in existing equipment, soldering in a controlled atmosphere requires either the retrofit of existing reflow ovens or the purchase of a specially designed nitrogen-capable oven. If a controlled atmosphere is introduced, it may be possible to use either a traditional RMA paste or a low-residue no-clean solder paste. In either case, it is important to ensure that the paste chosen is compatible with the atmosphere in which the soldering operation will be carried out, be it air or nitrogen.

### No-Clean Reflow Soldering

- Can be implemented in most existing equipment
- Eliminates the need for extensive worker re-training
- Eliminates relatively expensive cleaning costs
- Is enhanced when performed in an inert atmosphere.

## **No-Clean Reflow Soldering In Air**

The selection of a no-clean solder paste entails the consideration of several factors. The slump, tack, and deposition characteristics may be different from the current paste, thereby requiring new stencils of a different thickness or opening to deposit the same amount of paste. In addition, the reflow process window is smaller in a no-clean process. As is the case with wave soldering, the temperature profile may need to be changed to ensure proper activation of the flux, removal of volatiles, and

minimization of thermal shock. Consult with the paste manufacturer to verify the recommended thermal profile for each solder paste. Large boards with high heat sinking capability may pose a particular challenge. All of these process changes, however, can usually be accommodated in existing equipment.

### ***Retrofitting Existing Equipment for Controlled Atmosphere Soldering***

Most existing reflow ovens can be retrofitted for such operations. Some reflow ovens, however, are too open and consequently cannot be used for controlled atmosphere soldering. With such use, nitrogen would leak out of the oven at a rate which is too high to adequately carry out the soldering procedure to desired results. Therefore, new equipment will be required to replace these ovens.

Retrofitting reflow machines so that they can maintain a nitrogen atmosphere involves several procedures. First, the machine should be checked thoroughly for leaks and all leaks should be sealed to ensure that oxygen does not enter the machine. Second, nitrogen supply lines must be added to introduce gas into the preheat and reflow modules of the oven. These supply lines should also be checked for leaks. Third, an oxygen monitor should be installed to allow workers to keep track of the amount of oxygen present during soldering. Finally, curtains must be installed at the entrance to the preheat zone and at the exit from the reflow zone to reduce air penetration into the machine and to trap nitrogen inside.

### ***New Equipment Options for Controlled Atmosphere Soldering***

Although it is usually not necessary to invest in new equipment in order to implement a no-clean reflow soldering process, soldering in a controlled atmosphere may require new equipment. This need arises when the existing oven is not able to be adequately sealed to hold nitrogen. Since traditional ovens are not designed to enclose a gas within the preheat and solder modules, significant leaks may occur when attempting to seal these areas. No-clean reflow soldering machines are similar to conventional reflow ovens but have an open-tunnel with curtains at the entrance and exit to allow the use of a controlled atmosphere. In these machines, the curtains enclose the preheat, ramp-up, and solder modules and trap the nitrogen gas in the machine.